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TECHNICAL MEMORANDUM 1404

A DIGITAL COMPUTER PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTICS

FORREST L. McMAINS

ACMS 5523.11.565

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APRIL 1964

PICATINNY ARSENAL
DOVER, NEW JERSEY

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A DIGITAL COMPUTER PROGRAM
FOR
HIRSCHFELDER INTERIOR BALLISTICS

BY

FORREST L. McMAINS

AMCMS 5523.11.565 APRIL 1964

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ABSTRACT

A digital computer program was written which will perform interior ballistic calculations on an IBM 709 or IBM 7090. A brief description is given as well as an outline of the method of analysis which this program uses. Examples are presented and both input and output formats are discussed.

CONCLUSIONS

It is not the purpose of this report to evaluate or verify the accuracy of the Hirschfelder System on Interior Ballistics. Its only purpose is to describe a digital computer program which will perform the Hirschfelder calculations.

The reader will note that the results of the hand calculations given in Part IV correspond exactly to the computer results given in Appendix B.

INTRODUCTION

This report describes a digital computer program for performing the interior ballistic calculations of J. O. Hirschfelder.

The Hirschfelder System was developed between 1942 and 1945 and makes these basic assumptions:

1. A "first-degree burning law" is used in finding solutions to the fundamental ballistic equations.

2. The powder gas is distributed according to Kent's solution of the problem of the motion of the powder gas.

3. The heat lost to the bore up to any instant is proportional to the square of the velocity.

4. The friction of the projectile is taken as equivalent to a resisting pressure on the base of the projectile which is equal to a constant fraction of the average pressure.

This report's findings are divided into four parts:

The first part discusses the input and output formats.

The second part is devoted to a study of the basic equations used in the program. (It is assumed that the calculations found in Part II will be used in conjunction with Reference 1.)

The third part is a brief presentation of program logic.

In Part IV an example is given in which Cases 2, 3 and 4 are presented.

The program will solve four different types of problems (cases). In Case 1, various ϕ's are given along with maximum pressure and the computer will find velocity and web. In Case 2, charge and maximum pressure are given and web and velocity are found. In Case 3, charge and velocity are given and web and maximum pressure are found. In Case 4, charge, velocity and web are given and the burning constant is found.

The appendices include tables giving propellant codes and constants, the program output for the example given in Part IV and also the complete Fortran Program.

The reference used is a revision and consolidation of seven progress reports on interior ballistics written by J. O. Hirschfelder and others of the staff of the Geophysical Laboratory, Carnegie Institution of Washington (Reference 1).

DISCUSSION

PART I - INPUT AND OUTPUT FORMATS

Input Format

The first 104 data cards will be the same for any group of runs. These cards incorporate constant tabular values (Part III of this report).

Following this set of cards, any number of runs may be included provided each run is in correct sequence. For each run, the following format is used.

Card 1

Space 1 is reserved for a numerical code giving the type of problem to be solved. "1" means that maximum pressure and parameters ϕ's are given and web and velocity are to be found. "2" means that charge and pressure are given and web and velocity are to be found. "3" means that charge and velocity are given and maximum pressure and web are to be found. "4" means that charge, velocity and web are given and the burning constant is to be found.

Spaces 2 and 3 are reserved for a numerical code which denotes the propellant to be used in accordance with Table 1. The propellant constants are (given in Table 2) automatically selected from the memory of the machine. If no propellant code is specified or if it is given as "99," these constants must be given as part of the data, appearing on Card 2 below.

Space 4 is reserved for the code form function. A "1" denotes a propellant of single perforation. A "2" denotes a multiperforated propellant (for example, seven-perforated grains).

Space 5 is reserved for the number N of ϕ's used. Since the maximum number of ϕ's used is five, $0 < N \leq 5$. Space 6 is left blank and Spaces 7-12 are reserved for the weapon in millimeters.

Spaces 13-18 are reserved for the projectile weight in pounds.

Spaces 19-24 are reserved for the chamber volume in cubic inches.

Spaces 25-30 are reserved for the travel in inches.

Spaces 31-36 are reserved for the maximum pressure in psi.

Spaces 37-42 are reserved for the charge in pounds.

Spaces 43-48 are reserved for the muzzle velocity in ft/sec.

Spaces 49-54 are reserved for the web in inches.

Spaces 55-62 are reserved for the burning constant.

Spaces 63-64, 65-66, 67-68, 69-70, 71-72 are reserved for the values of ϕ's.

Card 2 (This card is only required if no propellant code - Spaces 2 and 3 above - is given or is given as "99.")

Spaces 1-6 are reserved for the propellant constant a.

Spaces 7-12 are reserved for the propellant constant a^o.

Spaces 13-18 are reserved for the propellant density in lbs/in^3.

Spaces 19-24 are reserved for the propellant co-volume in in^3/lbs.

Spaces 25-30 are reserved for the propellant force in ft-lbs/lb.

Most of these values must be punched on the card with a decimal point. The exceptions are:

> The codes: Spaces 1-4.
>
> The burning constant which may be given to eight significant digits.
>
> The ϕ's less than unity. The values for ϕ are 0.05, 0.10, 0.05, ..., 0.95, 1.00 and are punched as 05, 10, 15,..., 95, 1.

Output Format

The output will list all input data as well as the calculated loading densities, tabular values γ and Ƶ; velocities, pressures, web or burning constants depending on the problem being solved. If the problem is of Type 1 or 2 and the ϕ's given as input do not result in optimum efficiency, consecutive ϕ's are tried in an effort to improve the results.

ϕ, $\overset{o}{P_p}$, E_m, γ, Ƶ are referred to as "PHI," "PPϕ," "XIM," "GAMMA" and "ƵS" respectively.

An example of this program's output is in Appendix B.

PART II - NUMERICAL CALCULATIONS

Let W denote the weapon (caliber) in millimeters.
Let M denote the projectile weight in lbs.
Let V_c denote the chamber volume in in^3.
Let L denote the length of travel in in^3.
Let PMAX denote the maximum pressure in psi.
Let POPR denote the operating pressure in psi.
Let B denote the burning constant in (in/sec)/psi.
Let C denote the charge in lbs.
Let WEB denote the web in inches.
Let $\triangle$ denote the loading density in gms/cc.
Let V_m denote the velocity in ft/sec.

The following are constant for the propellant. Their values are given in Table 2 of Appendix A.

Let a and a^o denote the two "propellant constants" in in^3/lb.
Let ρ denote the propellant density in lbs/in^3.
Let η denote the propellant covolume in in^3/lb.
Let F denote the propellant force in ft-lbs/lb.

If C is given (Cases 2, 3 and 4), $\triangle$ (the loading density) is obtainable: $\triangle = C/V_c$

To facilitate the calculations, the parameter ϕ is used and is equal to the value: $a/\left(\frac{1}{\triangle} - \frac{1}{\rho}\right)$

From $\phi = a/\left(\frac{1}{\triangle} - \frac{1}{\rho}\right)$, the equalities

$$\phi\left(\frac{1}{\triangle} - \frac{1}{\rho}\right) = a$$

$$\frac{1}{\triangle} - \frac{1}{\rho} = \frac{a}{\phi}$$

$$\frac{1}{\triangle} = \frac{1}{\rho} + \frac{a}{\phi}$$

$$\triangle = 1/\left(\frac{1}{\rho} + \frac{a}{\phi}\right)$$

are derived. Therefore, if n ϕ's are chosen, $\phi_1, \ldots, \phi_n$ (as in Case 1)

and C is not given, each of the n $\triangle$'s are calculable:

$$\triangle i = 1/\left(\frac{1}{\rho} + \frac{a}{\phi i}\right)$$

and hence $C_i = \triangle i \cdot V_c$, $i = 1, \ldots, n$

Let A denote the bore area of the projectile.

$$A = \left(\frac{w}{25.4} \cdot \frac{1}{2}\right)^2 \cdot \pi$$

Let $X = (Vc + A \cdot L)/Vc$

Let $\mathcal{E}_m = (a\triangle)/(X - \eta\triangle)$

Let $P_{pi}{}^{o} = a^{o}\, PMAX \left(\frac{M + \frac{Ci}{3}}{M + \frac{Ci}{2}}\right)$ where

PMAX = 1.15 POPR

Knowing the value of ϕi and $P_{pi}{}^{o}$, the values of Z_i and γi for each i are now obtainable from Tables 4, 6, 8 and 10 in Reference 1. Tables 4 and 6 give $Z i$ and γi, respectively, for single-perforated propellants. Table 8 and 10 give $Z i$, and γi, respectively, for seven-perforated propellants.

$$\text{Let } mi' = \frac{1.02\left(m + \frac{Ci}{3.1}\right)}{32.175}$$

The velocity Vm_i is then equal to the value

$$\sqrt{\left(1 - \gamma i\, \mathcal{E}m^{0.3}\right) \frac{2CiF}{0.3m_i'}}, \quad i = 1, \ldots, n$$

Consider the case (Case 3) when C and Vm are given. Here Ci = C for each i and $\phi i, P^{o}_{pi}, Z i, \gamma i$ and m_i' all have the single values ϕ, P^{o}_{p}, Z, γ; and m' respectively.

Therefore, since $Vm = \sqrt{(1 - \gamma\mathcal{E}m^{0.3})\dfrac{2CF}{0.3m'}}$

$$Vm^2 = (1 - \gamma\mathcal{E}m^{0.3})\frac{2CF}{0.3m'}$$

$$(\gamma\mathcal{E}m^{0.3})\frac{2CF}{0.3m'} = \frac{2CF}{0.3m'} - Vm^2$$

$$\gamma = \left(\frac{CF}{0.15m'} - Vm^2\right)\frac{0.15m'}{\mathcal{E}m^{0.13} \cdot CF}$$

$$\gamma = \left(1 - \frac{0.15m' \, Vm^2}{CF}\right) / \mathcal{E}m^{0.3}$$

Knowing γ and ϕ, Pp^o is obtainable from Tables 6 or 10.

From $Pp^o = a^o \, PMAX \left[\dfrac{M + \frac{c}{3}}{M + \frac{c}{2}}\right]$

we find $PMAX = \dfrac{Pp^o}{a^o} \left[\dfrac{M + \frac{c}{2}}{M + \frac{c}{3}}\right]$

Knowing Pp^o and ϕ, Z is obtainable from Table 4 or 6

Let $\mathcal{E}m^{0.3} = S$
Let $(1 - 0.1485\ Z) / \gamma = Ts$
Let $(1 - 0.242\ Z) / \gamma = Tm$

When a single-perforated propellant is used, Ts is calculated and the point of optimum efficiency is when S and Ts are equal. In this case

$$WEB = (B/A)\sqrt{\frac{CFm'Z}{0.99}}$$

However, when a multiperforated propellant is used, Tm is calculated and the point of optimum efficiency is when S and Tm are equal. In this case

$$WEB = (B/A)\sqrt{\frac{CFm'Z}{1.369}}$$

PART III - PROGRAM LOGIC

Tables 8, 10, 4 and 6 of Reference 1 appear in the first 104 data cards. As I = 1, 20 and J = 1, 47; Cards 1-24 give A(I, J), the values in Table 8. Cards 25-48 give C(I, J), the values in Table 10. Cards 49-76 give E(I, J), the values in Table 4 and Cards 77-104 give F(I, J), the values in Table 6. $I = Pp^o/2,000$ where $Pp^o = 2,000, 4,000, 6,000, \ldots, 90,000, 95,000, 100,000$. $J = 20\phi$ where $\phi = 0.05, 0.10, \ldots, 0.95, 1.0$.

Linear interpolations were made within these tables when δ and Z are known and Pp^o is to be found. No attempt was made to interpolate between the ϕ's; instead, the tabular ϕ closest to the calculated ϕ has been selected.

PART IV -- EXAMPLES

90mm, Gun, M41

1. Gun constants

Projectile weight M	12.65 lbs.
Chamber volume Vc	300 in.^{3}
Propellant Type	M17 (M.P.)
Total Travel L	155 in.

2. Case 4

Given:

Charge C	8.58 lbs.
Maximum Pressure PMAX	50,500 psi
Velocity Vm	4,000 f/s
Web	0.052 in.

$$\triangle = \frac{c}{Vc} = \frac{8.58}{300} = 0.0286$$

$$\phi = \frac{a}{\frac{1}{\triangle} - \frac{1}{P}} = \frac{12.92}{\frac{1}{0.0286} - \frac{1}{0.0603}} = \frac{12.92}{34.965 - 16.5837}$$

$$= \frac{12.92}{18.38126}$$

$$= 0.70289 \approx 0.70$$

(where a and ρ are found in Table 2 (9) of Appendix A).

$$Pp^o = a^o PMAX \left[\frac{M + \frac{c}{3}}{M + \frac{c}{2}}\right] = (0.851)(50,500) \left[\frac{12.65 + \frac{8.58}{3}}{12.65 + \frac{8.58}{2}}\right]$$

$$= (42975.5) \cdot \left[\frac{15.51}{16.94}\right]$$

$$= (42975.5)(0.915584) = 39347.697$$

(where a^o is also found in Table 2).

Z = 1.763 by Table 8 in Reference 1.

$$m' = \frac{1.02(M + \frac{C}{3.1})}{32.174} = \frac{1.02 \cdot (12.65 + \frac{8.58}{3.1})}{32.174}$$

$$= \frac{1.02(15.41777)}{32.174} = \frac{15.7261}{32.174}$$

$$= 0.48878$$

$$A = (\frac{90}{25.4} \cdot 0.5)^2 (3.1416) = (1.772)^2 (3.1416) = 9.8607$$

Since $\text{Web} = (B/A) \sqrt{\frac{CFm'Z}{1.369}}$

$$0.052 = \frac{B}{9.8607} \cdot \sqrt{\frac{(8.58)(364{,}000)(0.48878)(1.763)}{1.369}}$$

$$0.5127 = B \cdot \sqrt{\frac{2681157.356}{1.369}}$$

$$0.5118 = B \cdot \left(\frac{1637.424}{1.17}\right)$$

$$0.598806 = 1637.424\,B$$

$$B = 0.0003657$$

3. Case 2

Given: Charge C ---------------------- 8.58 lbs.

Maximum Pressure PMAX ------ 50,500 psi

Δ = 0.0286, ϕ = 0.70; Pp^o = 39347.697

γ = 1.410 by Table 10 in Hirschfelder

A = 9.8607

$$X = \frac{Vc + A \cdot L}{Vc} = \frac{300 + (9.8607)(155)}{300} = \frac{1828.4085}{300}$$

$$= 6.0947$$

$$\mathcal{E}m = \frac{(12.92)(0.0286)}{6.0947 - (29.50)(0.0286)}$$

$$= \frac{0.3695}{6.0947 - 0.8437} = \frac{0.3695}{5.251} = 0.07037$$

$$S = \mathcal{E}m^{0.3} = 0.451$$

$$Vm = \sqrt{(1 - \gamma\, \mathcal{E}m^{0.3}) \quad \frac{2CF}{0.3m}}$$

$$= \sqrt{\left[1 - (1.410)(0.451)\right] \cdot \frac{2(8.58)(364000)}{(0.3)(0.48878)}}$$

$$= \sqrt{(1 - 0.6359) \cdot \left(\frac{6246240}{0.14669}\right)}$$

$$= \sqrt{\frac{2274255.984}{0.14669}}$$

$$= \frac{1508.4577}{0.383} = 3938.532$$

$$Tm = \frac{1 - 0.242\, Z}{\gamma} = \frac{1 - (0.242)(1.763)}{1.410} = \frac{0.57393}{1.410} = 0.407$$

Since $S = 0.451 > 0.407 = Tm$, burning is taking place outside the weapon. To attain optimum conditions, new and smaller ϕ's (and hence new charges) may be chosen in an effort to minimize $|S - Tm|$. This was done on the computer and the results are in Appendix B for Cases 1 and 2.

It is obvious that the web, calculated with $B = 0.0003657$, will be 0.052 since the equation for web was used in Case 4 to find B.

4. Case 3

Given: Charge C ------------------------ 8.58 lbs.

Velocity Vm -------------------- 4,000 f/s

$$\delta = (1 - \frac{0.15m' \, Vm^2}{CF}) / \mathscr{E}m^{0.3}$$

$$= \frac{1 - \frac{(0.15)(0.48878)(4000)^2}{(8.58)(364,000)}}{0.451}$$

$$\frac{1 - \frac{1173072}{3123120}}{0.451} = \frac{1 - 0.37561}{0.451} = \frac{0.62439}{0.451} = 1.384$$

Since $\phi = 0.70$, $Pp^o = 41561.1367$ by Table 10 in Reference 1. Therefore, $Z = 1.693$

$$PMAX = \frac{Pp^o}{a^o} \left[\frac{M + \frac{c}{2}}{M + \frac{c}{3}} \right]$$

$$= \left(\frac{41561.1367}{0.851}\right) \left(\frac{12.65 + \frac{8.58}{2}}{12.65 + \frac{8.58}{3}}\right)$$

$$= \left(\frac{41561.1367}{0.851}\right) \cdot \left(\frac{16.94}{15.51}\right)$$

$$= (41561.1367)(1.2834)$$

$$= 53340.792 \text{ psi}$$

$Z = 1.693$ by Table 8 in the reference.

$$\text{Therefore, Web} = \frac{0.0003657}{9.8607} \cdot \frac{\sqrt{(8.58)(364000)(0.48878)(1.693)}}{1.369}$$

$$= \frac{0.0003657}{9.8607} \cdot \frac{\sqrt{258439597.29}}{1.17}$$

$$= \frac{(0.0003657)(16076.0566)}{11.537}$$

$$= \frac{0.05879}{11.537}$$

$$= 0.005096$$

REFERENCE

1. C. F. Curtiss and J. W. Wrench Jr., Interior Ballistics: A Consolidation and Revision of Previous Reports, Interior Ballistics I to VII, Inclusive, July 1945, Geophysical Laboratory, Carnegie Institution of Washington, NDRC Report No. A-397, OSRD Report No. 6468.

APPENDICES

APPENDIX A

TABLES

TABLE 1

PROPELLANT CODES

Propellant	Code
M1	1
M2	2
M5	5
M6	6
M9	9
M10	10
M14	14
M15	15
M17	17
T25	25
T28	28
T34	34
T36	36

In order for the propellant constants to be read in as part of the input (data Card 2), the code is "99."

TABLE 2

PROPELLANT CONSTANTS

In the following table, a and a^o represent the propellant "a" - constants; ρ represents the propellant density in lbs/in^3, η represents propellant covolume in $in^3/lbs.$, and F represents the propellant force in ft. lbs/lbs.

Propellant	a	a^o	ρ	η	F
M1	12.92	1.015	0.0567	30.57	305,000
M2	11.16	0.743	0.0597	27.91	360,000
M5	10.74	0.725	0.0596	27.52	355,000
M6	12.41	0.938	0.0571	29.92	317,000
M9	9.02	0.566	0.659	25.97	382,000
M10	11.15	0.788	0.0602	27.76	339,000
M14	12.36	0.906	0.058	29.54	327,000
M15	14.50	1.034	0.06	31.17	336,000
M17	12.92	0.851	0.0603	29.50	364,000
T25	11.57	0.786	0.0585	28.66	353,000
T28	11.68	0.786	0.0585	28.77	356,000
T34	14.07	1.007	0.0596	30.85	335,000
T36	12.59	0.828	0.06	29.26	364,000

APPENDIX B

PROGRAM OUTPUT FOR CASES 1-4

I N P U T

```
CASE = 1
PRØPELLANT CØDE = 17
CØDE FØRM FUNCTIØN = 2
WEAPØN W (MM) =       90.0000
PRØJ.WT. PJW (LBS.) =       12.6500
CHAMBER VØLUME VC (C.IN) =      300.0000
TRAVEL TRAV (IN) =      155.0000
MAX PRESSURE PMAX (PSI) =   50500.0000
ØPERATING PRESSURE PØPR (PSI) =    43913.0435
PRØP. CØVØLUME ETA (C.IN/LBS) =       29.5000
PRØP. DENSITY RHØ (LBS/C.IN) =        0.0603
PRØP. FØRCE F (FT.LBS/LBS) =   364000.0000
PRØP. CØNSTANTS A,AØ, =       12.9200          0.8510
BURN.CØNSTANT B =    0.00036573
BØRE AREA =       9.8607
```


Ø U T P U T

PHI	L.DENSITY	CHARGE	PPØ	XIM	GAMMA	ZS	VELØCITY	S	T	WEB
0.050	0.004	1.09	42383.3135	0.008	-0.	-0.	2534.419	0.234	0.	0.
0.300	0.017	5.03	40600.0542	0.039	1.527	0.758	3383.761	0.377	0.535	0.025117025
0.500	0.024	7.07	39846.1870	0.056	1.422	1.294	3808.135	0.422	0.483	0.039799377
0.700	0.029	8.56	39353.5654	0.070	1.410	1.763	3937.836	0.451	0.407	0.051929250

THE PØINT ØF ØPTIMUM EFFICIENCY IS WHEN S AND T ARE EQUAL

TRUE PHI IS GREATER THAN 0.5000 WHERE S = 0.4221 AND T = 0.4832

0.55	0.025	7.49	39704.6367	0.060	1.413	1.407	3861.345	0.430	0.467	0.042898998
0.60	0.026	7.87	39576.5127	0.064	1.404	1.531	3909.213	0.438	0.448	0.046060152
0.65	0.027	8.23	39459.9917	0.067	1.405	1.646	3929.880	0.445	0.428	0.049026169

I N P U T

```
CASE = 2
PRØPELLANT CØDE = 17
CØDE FØRM FUNCTIØN = 2
WEAPØN W (MM) =       90.0000
PRØJ.WT. PJW (LBS.) =      12.6500
CHAMBER VØLUME VC (C.IN) =      300.0000
TRAVEL TRAV (IN) =      155.0000
MAX PRESSURE PMAX (PSI) =   50500.0000
ØPERATING PRESSURE PØPR (PSI) =   43913.0435
PRØP. CØVØLUME ETA (C.IN/LBS) =      29.5000
PRØP. DENSITY RHØ (LBS/C.IN) =       0.0603
PRØP. FØRCE F (FT.LBS/LBS) =  364000.0000
PRØP. CØNSTANTS A,AØ, =      12.9200           0.8510
BURN.CØNSTANT B =   0.00036573
BØRE AREA =       9.8607
```

Ø U T P U T

PHI	L.DENSITY	CHARGE	PPØ	XIM	GAMMA	ZS	VELØCITY	S	T	WEB
0.70	0.029	8.58	39347.6973	0.070	1.410	1.763	3938.532	0.451	0.407	0.051998682

THE PØINT ØF ØPTIMUM EFFICIENCY IS WHEN S AND T ARE EQUAL

TRUE PHI IS LESS THAN 0.7029 WHERE S = 0.4510 AND T = 0.4067

PHI	L.DENSITY	CHARGE	PPØ	XIM	GAMMA	ZS	VELØCITY	S	T	WEB
0.65	0.027	8.25	39453.5811	0.067	1.405	1.646	3930.916	0.445	0.428	0.049098566
0.60	0.026	7.89	39569.4810	0.064	1.404	1.531	3910.559	0.438	0.448	0.046135731

INPUT

```
CASE = 3
PRØPELLANT CØDE = 17
CØDE FØRM FUNCTIØN = 2
WEAPØN W (MM) =        90.0000
PRØJ.WT. PJW (LBS.) =       12.6500
CHAMBER VØLUME VC (C.IN) =      300.0000
TRAVEL TRAV (IN) =      155.0000
CHARGE CH(1) (LBS) =        8.5800
VELØCITY VM(1) (F/S) =     4000.0000
PRØP. CØVØLUME ETA (C.IN/LBS) =       29.5000
PRØP. DENSITY RHØ (LBS/C.IN) =        0.0603
PRØP. FØRCE F (FT.LBS/LBS) =  364000.0000
PRØP. CØNSTANTS A,AØ, =        12.9200          0.8510
BURN.CØNSTANT B =    0.00036573
BØRE AREA =        9.8607
```

ØUTPUT

PHI	L.DENSITY	CHARGE	PPØ	XIM	GAMMA	ZS	PRESSURE	S	T	WEB
0.703	0.029	8.58	41561.1367	0.070	1.384	1.693	53340.792	0.451	0.426	0.050960869

I N P U T

```
CASE = 4
PRØPELLANT CØDE = 17
CØDE FØRM FUNCTIØN = 2
WEAPØN W (MM) =       90.0000
PRØJ.WT. PJW (LBS.) =       12.6500
CHAMBER VØLUME VC (C.IN) =      300.0000
TRAVEL TRAV (IN) =       155.0000
MAX PRESSURE PMAX (PSI) =     50500.0000
ØPERATING PRESSURE PØPR (PSI) =    43913.0435
CHARGE (LBS) =        8.5800
VELØCITY (F/S) =     4000.0000
WEB =         0.0520
PRØP. CØVØLUME ETA (C.IN/LBS) =       29.5000
PRØP. DENSITY RHØ (LBS/C.IN) =        0.0603
PRØP. FØRCE F (FT.LBS/LBS) =    364000.0000
PRØP. CØNSTANTS A,AØ, =        12.9200           0.8510
BØRE AREA =       9.8607
```

Ø U T P U T

PHI	L.DENSITY	CHARGE	PPØ	XIM	GAMMA	ZS	VELØCITY	S	T	B
0.703	0.029	8.58	39347.6973	0.070	1.410	1.763	4000.000	0.451	0.407	0.000365734

THE PØINT ØF ØPTIMUM EFFICIENCY IS WHEN S AND T ARE EQUAL

APPENDIX C

FORTRAN PROGRAM FOR INTERIOR BALLISTICS

FØRTRAN PRØGRAM FØR HIRSCHFELDER INTERIØR BALLISTIC CALCULATIØNS

```
      DIMENSIØN A(25,55),B(25),C(25,55),D(25),PH(15),DELTA(15),CH(15),PØ
     1P(15),XIM(15),ZS(15),GAMMA(15),H(15),VM(15),S(15),T(15),WEB(15),E(
     225,55),F(25,55),AB(50),ABV(50)
      READ INPUT TAPE 2,2,(A(1,J),J=1,4),(A(2,J),J=2,8),(A(3,J),J=3,13),
     1(A(4,J),J=4,19),(A(5,J),J=5,24),(A(6,J),J=5,31),(A(7,J),J=6,38),(A
     2(8,J),J=7,45),(A(9,J),J=8,47),(A(10,J),J=9,47),(A(11,J),J=10,47),(
     3A(12,J),J=11,47),(A(13,J),J=12,47),(A(14,J),J=13,47),(A(15,J),J=14
     4,47),(A(16,J),J=15,47),(A(17,J),J=16,47),(A(18,J),J=17,47),(A(19,J
     5),J=18,47),(A(20,J),J=19,47),(B(I),I=1,5)
    2 FØRMAT(24F3.2/(24F3.2))
      READ INPUT TAPE 2,3,(C(1,J),J=1,4),(C(2,J),J=2,8),(C(3,J),J=3,13),
     1(C(4,J),J=4,19),(C(5,J),J=5,24),(C(6,J),J=5,31),(C(7,J),J=6,38),(C
     2(8,J),J=7,45),(C(9,J),J=8,47),(C(10,J),J=9,47),(C(11,J),J=10,47),(
     3C(12,J),J=11,47),(C(13,J),J=12,47),(C(14,J),J=13,47),(C(15,J),J=14
     4,47),(C(16,J),J=15,47),(C(17,J),J=16,47),(C(18,J),J=17,47),(C(19,J
     5),J=18,47),(C(20,J),J=19,47),(D(I),I=1,5)
    3 FØRMAT(24F3.2/(24F3.2))
      READ INPUT TAPE 2,8,(E(1,J),J=1,7),(E(2,J),J=2,15),(E(3,J),J=3,25)
     1,(E(4,J),J=4,35),(E(5,J),J=4,46),(E(6,J),J=5,47),(E(7,J),J=6,47),(
     2E(8,J),J=7,47),(E(9,J),J=8,47),(E(10,J),J=9,47),(E(11,J),J=10,47),
     3(E(12,J),J=11,47),(E(13,J),J=12,47),(E(14,J),J=13,47),(E(15,J),J=1
     44,47),(E(16,J),J=15,47),(E(17,J),J=17,47),(E(18,J),J=18,47),(E(19,
     5J),J=19,47),(E(20,J),J=20,47)
    8 FØRMAT(24F3.2/(24F3.2))
      READ INPUT TAPE 2,8,(F(1,J),J=1,7),(F(2,J),J=2,15),(F(3,J),J=3,25)
     1,(F(4,J),J=4,35),(F(5,J),J=4,46),(F(6,J),J=5,47),(F(7,J),J=6,47),(
     2F(8,J),J=7,47),(F(9,J),J=8,47),(F(10,J),J=9,47),(F(11,J),J=10,47),
     3(F(12,J),J=11,47),(F(13,J),J=12,47),(F(14,J),J=13,47),(F(15,J),J=1
     44,47),(F(16,J),J=15,47),(F(17,J),J=17,47),(F(18,J),J=18,47),(F(19,
     5J),J=19,47),(F(20,J),J=20,47)
    9 FØRMAT(24F3.2/(24F3.2))
    1 READ INPUT TAPE 2,4,KASE,KØDE,M,N,W,PJW,VC,TRAV,PMAX,CH(1),VM(1),W
     1EB(1),Y,(PH(I),I=1,N)
    4 FØRMAT(I1,I2,2I1,1X,8F6.0,F8.8,5F2.2)
      PØPR=PMAX/1.15
      DØ 500 I=1,20
      A(I,46)=A(I,47)
      A(I,47)=A(I,50)
      C(I,46)=C(I,47)
      C(I,47)=C(I,50)
      E(I,46)=E(I,47)
      E(I,47)=E(I,50)
      F(I,46)=F(I,47)
      F(I,47)=F(I,50)
  500 CØNTINUE
      IF(KØDE-99)60,61,60
   61 READ INPUT TAPE 2,62,V,AØ,RHØ,ETA,U
   62 FØRMAT(5F6.0)
      GØ TØ 300
   60 IF(KØDE-1)61,64,63
   64 V=12.92
      AØ=1.015
      RHØ=0.0567
      ETA=30.57
      U=305000.
```

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```
63 IF(KØDE-2)65,66,65
66 V=11.16
   AØ=0.743
   RHØ= 0.0597
   ETA= 27.91
   U= 360000.
65 IF(KØDE-5)67,68,67
68 V=10.74
   AØ=0.725
   RHØ = 0.0596
   ETA = 27.52
   U = 355000.
67 IF(KØDE-6)69,70,69
70 V=12.41
   AØ = 0.938
   RHØ = 0.0571
   ETA = 29.92
   U = 317000.
69 IF(KØDE-9)71,72,71
72 V= 9.02
   AØ = 0.566
   RHØ = 0.6590
   ETA = 25.97
   U = 382000.
71 IF(KØDE - 10)73,74,73
74 V= 11.15
   AØ = 0.788
   RHØ =  0.0602
   ETA =  27.76
   U =  339000.
73 IF(KØDE-14)75,76,75
76 V = 12.36
   AØ = 0.906
   RHØ = 0.0582
   ETA = 29.54
   U = 327000.
75 IF(KØDE-15)77,78,77
78 V = 14.50
   AØ = 1.034
   RHØ = 0.0600
   ETA = 31.17
   U = 336000.
77 IF(KØDE-17)79,80,79
80 V= 12.92
   AØ = 0.851
   RHØ = 0.0603
   ETA = 29.50
   U = 364000.
79 IF(KØDE-25)81,82,81
82 V = 11.57
   AØ = 0.786
   RHØ = 0.0585
   ETA = 28.66
   U = 353000.
81 IF(KØDE-28)83,84,83
84 V = 11.68
```

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```
      AØ = 0.786
      RHØ = 0.0585
      ETA = 28.77
      U = 356000.
   83 IF(KØDE-34)85,86,85
   86 V = 14.07
      AØ = 1.007
      RHØ = 0.0596
      ETA = 30.85
      U = 335000.
   85 IF(KØDE-36)300,88,300
   88 V = 12.59
      AØ = 0.828
      RHØ = 0.060
      ETA = 29.26
      U = 364500.
  300 STEVØ = 0.0
      IF(KASE-1)100,31,100
  100 IF(KASE-2)102,103,102
  103 N=1
      I=1
      DELTA(1)=CH(1)/VC
      PH(1)=V/((1./DELTA(1))-(1./RHØ))
      GØ TØ 106
  102 IF(KASE-3)104,105,600
  600 I=2
      DELTA(I)=CH(1)/VC
      PH(I)=V/((1./DELTA(I))-(1./RHØ))
      CH(2)=CH(1)
      WEB(2)=WEB(1)
      VM(2)=VM(1)
      GØ TØ 106
  105 DELTA(1)= CH(1)/VC
      PH(1)=V/((1./DELTA(1))-(1./RHØ))
      AREA = ((W/25.4)**2)*(3.1416/4.)
      X = (VC + (AREA*TRAV))/VC
      XIM(1) = (V*DELTA(1))/(X-(ETA*DELTA(1)))
      S(1) = XIM(1)**0.3*
      H(1) = .0317*(PJW+(.3226*CH(1)))
      GAMMA(1) =(1.-((.15*H(1)*(VM(1)**2))/(CH(1)*U)))/S(1)
      Q = (PH(1)*20.) + 0.4
      L=Q
      I2=0
      DØ 120 I=1,20
      IF(L-I)120,140,120
  140 I2=I
  120 CØNTINUE
      IF(I2)122,121,122
  121 WRITE ØUTPUT TAPE 3,123,KASE,PH(1)
  123 FØRMAT(1H1,10X,7HA CASE I3,63H TYPE PRØBLEM HAS BEEN REJECTED HERE
     1 BECAUSE CALCULATED PHI IS F10.4,38H FØR WHICH THE TABLES ARE NØT
     2ADEQUATE)
      GØ TØ 40
  122 IF(M-1)108,108,107
  107 DØ 109 I=1,47
      ABV(I) = ABSF(C(L,I) - GAMMA(1))
```

```
  109 CØNTINUE
      VAL = ABV(1)
      DØ 129 I=1,47
      VAL = MIN1F(VAL,ABV(I))
  129 CØNTINUE
      DØ 110 I=1,47
      IF(ABV(I) - VAL) 110,112,110
  112 K = I
      TK = K
  110 CØNTINUE
      IF(GAMMA(1) - C(L,K))113,114,115
  113 R=(C(L,K)-GAMMA(1))/(C(L,K)-C(L,K+1))+TK
      GØ TØ 116
  114 R=TK
      GØ TØ 116
  115 R=(C(L,K-1)-GAMMA(1))/(C(L,K-1)-C(L,K))+TK-1.
  116 PØP(1)=R*2000.
      J=R
      Z=J
      ZS(1) = A(L,J)-(ABSF(R-Z)*ABSF(A(L,J) - A(L,J+1)))
      T(1)=(1.-.242*ZS(1))/GAMMA(1)
  151 WEB(1)=Y/SQRTF((1.369*AREA**2)/(CH(1)*U*H(1)*ZS(1)))
      PMAX=(PØP(1)/AØ)*(1.+(CH(1)/(6.*PJW+2.*CH(1))))
      GØ TØ 137
  108 DØ 130 I=1,47
      ABV(I)=ABSF(F(L,I)-GAMMA(1))
  130 CØNTINUE
      VAL=ABV(1)
      DØ 131 I=1,47
      VAL=MIN1F(VAL,ABV(I))
  131 CØNTINUE
      DØ 132 I=1,47
      IF(ABV(I)-VAL)132,133,132
  133 K=I
      TK=K
  132 CØNTINUE
      IF(GAMMA(1)-F(L,K))150,134,135
  150 R=(F(L,K)-GAMMA(1))/(F(L,K)-F(L,K+1))+TK
      GØ TØ 136
  134 R=TK
      GØ TØ 136
  135 R=(F(L,K-1)-GAMMA(1))/(F(L,K-1)-F(L,K))+TK-1.
  136 PØP(1)=R*2000.
      J=R
      Z=J
      ZS(1)=E(L,J)-(ABSF(R-Z)*ABSF(E(L,J)-E(L,J+1)))
      T(1)=(1.-.1485*ZS(1))/GAMMA(1)
  161 WEB(1)=Y/SQRTF((0.990*AREA**2)/(CH(1)*U*H(1)*ZS(1)))
      PMAX=(PØP(1)/AØ)*(1.+(CH(1)/(6.*PJW+2.*CH(1))))
  137 WRITE ØUTPUT TAPE 3,138,KASE,KØDE,M,W,PJW,VC,TRAV,CH(1),VM(1),ETA,
     1RHØ,U,V,AØ,Y,AREA
  138 FØRMAT(1H1,50X,9HI N P U T//5X,7HCASE = I1/5X,18HPRØPELLANT CØDE =
     1 I2/5X,21HCØDE FØRM FUNCTIØN = I1,6H      /5X,16HWEAPØN W (MM) = F
     212.4/5X,22HPRØJ.WT. PJW (LBS.) = F12.4/5X,27HCHAMBER VØLUME VC (C.
     3IN) = F12.4/5X,19HTRAVEL TRAV (IN) = F12.4/5X,21HCHARGE CH(1) (LBS
     4) = F12.4/5X,23HVELØCITY VM(1) (F/S) = F12.4,10H          /5X,32HP
```

```
     5RØP. CØVØLUME ETA (C.IN/LBS) = F12.4/5X,31HPRØP. DENSITY RHØ (LBS/
     6C.IN) = F12.4/5X,29HPRØP. FØRCE F (FT.LBS/LBS) = F12.4/5X,24HPRØP.
     7 CØNSTANTS A,AØ, = F12.4,5X,F12.4/5X,18HBURN.CØNSTANT B = F12.8/5X
     8,12HBØRE AREA = F12.4)
      N=1
      WRITE ØUTPUT TAPE 3,89,(PH(I),DELTA(I),CH(I),PØP(I),XIM(I),GAMMA(I
     1),ZS(I),PMAX,S(I),T(I),WEB(I),I=1,N)
  89 FØRMAT(1X//50X,11HØ U T P U T//102H     PHI    L.DENSITY      CHARGE
     1    PPØ           XIM   GAMMA     ZS      PRESSURE          S        T
     2  WEB///(1X,F8.2,1X,F8.3,1X,F10.2,1X,F12.4,1X,F8.3,1X,F6.3,1X,F6.3
     3,1X,F12.3,1X,F8.3,1X,F8.3,1X,F12.9))
      GØ TØ 40
 153 WRITE ØUTPUT TAPE 3,155,KASE,KØDE,M,W,PJW,VC,TRAV,PMAX,PØPR,CH(1),
     1VM(1),WEB(1),ETA,RHØ,U,V,AØ,AREA
 155 FØRMAT(1H1,50X,9HI N P U T//5X,7HCASE = I1/5X,18HPRØPELLANT CØDE =
     1 I2/5X,21HCØDE FØRM FUNCTIØN = I1,6H      /5X,16HWEAPØN W (MM) = F
     212.4/5X,22HPRØJ.WT. PJW (LBS.) = F12.4/5X,27HCHAMBER VØLUME VC (C.
     3IN) = F12.4/5X,19HTRAVEL TRAV (IN) = F12.4/5X,26HMAX PRESSURE PMAX
     4 (PSI) = F12.4/5X,32HØPERATING PRESSURE PØPR (PSI) = F12.4/5X,15HC
     5HARGE (LBS) = F12.4/5X,17HVELØCITY (F/S) = F12.4/5X,6HWEB = F12.4,
     654H                                                         /5X,32HP
     7RØP. CØVØLUME ETA (C.IN/LBS) = F12.4/5X,31HPRØP. DENSITY RHØ (LBS/
     8C.IN) = F12.4/5X,29HPRØP. FØRCE F (FT.LBS/LBS) = F12.4/5X,24HPRØP.
     9 CØNSTANTS A,AØ, = F12.4,5X,F12.4/5X,12HBØRE AREA = F12.4)
      N=1
      WRITE ØUTPUT TAPE 3,700,PH(2),DELTA(2),CH(1),PØP(2),XIM(2),GAMMA(2
     1),ZS(2),VM(1),S(2),T(2),Y
 700 FØRMAT(1X//50X,11HØ U T P U T//102H     PHI    L.DENSITY      CHARGE
     1    PPØ           XIM   GAMMA     ZS      VELØCITY          S        T
     2     B///(1X,F8.2,1X,F8.3,1X,F10.2,1X,F12.4,1X,F8.3,1X,F6.3,1X,F6.3
     3,1X,F12.3,1X,F8.3,1X,F8.3,1X,F12.9))
      WRITE ØUTPUT TAPE 3,156
 156 FØRMAT(1X//30X,57HTHE PØINT ØF ØPTIMUM EFFICIENCY IS WHEN S AND T
     1ARE EQUAL)
 104 GØ TØ 40
  31 DØ 5 I = 1,N
      DELTA(I) = 1./((V/PH(I))+(1./RHØ))
      CH(I)=VC*DELTA(I)
 106 PØP(I)= PMAX*AØ*((PJW +CH(I)/3.)/(PJW +CH(I)/2.))
      AREA =((W/25.4)**2)*(3.1416/4.)
      X =(VC+(AREA*TRAV))/VC
      XIM(I)=(V*DELTA(I))/(X-(ETA*DELTA(I)))
      Q=(PH(I)*100.)/5.
      Q=Q+0.4
      R= PØP(I)/2000.
      R=R+(1./(10.**7))
      L=Q
      J=R
      Z=J
```



```
      IF(M-1)11,11,10
  11 ZS(I)=E(L,J)-(ABSF((PØP(I)/2000.)-Z)*ABSF(E(L,J)-E(L,J+1)))
      GAMMA(I)=F(L,J)-(ABSF((PØP(I)/2000.)-Z)*ABSF(F(L,J)-F(L,J+1)))
      H(I)=.0317*(PJW +(.3226*CH(I)))
      VM(I)=SQRTF((1.-GAMMA(I)*(XIM(I)**0.3))*((2.*CH(I)*U)/(0.3*H(I))))
      S(I)=XIM(I)**0.3
      T(I)=(1.-(.1485*ZS(I)))/GAMMA(I)
```

```
      WEB(I)=Y/SQRTF((0.990*AREA**2)/(CH(I)*U*H(I)*ZS(I)))
      IF(KASE-4) 5,162,162
  162 Y = WEB(1)*SQRTF((0.99*AREA**2)/(CH(1)*U*H(I)*ZS(I)))
      GØ TØ 153
   10 ZS(I)=A(L,J)-(ABSF((PØP(I)/2000.)-Z)*ABSF(A(L,J)-A(L,J+1)))
      GAMMA(I)=C(L,J)-(ABSF((PØP(I)/2000.)-Z)*ABSF(C(L,J)-C(L,J+1)))
      H(I)=.0317*(PJW +(.3226*CH(I)))
      VM(I)=SQRTF((1.-GAMMA(I)*(XIM(I)**0.3))*((2.*CH(I)*U)/(0.3*H(I))))
      S(I)=XIM(I)**0.3
      T(I)=(1.-(.242*ZS(I)))/GAMMA(I)
      WEB(I)=Y/SQRTF((1.369*AREA**2)/(CH(I)*U*H(I)*ZS(I)))
      IF(KASE-4) 5,152,152
  152 Y = WEB(1)*SQRTF((1.369*AREA**2)/(CH(1)*U*H(I)*ZS(I)))
      GØ TØ 153
    5 CØNTINUE
      IF(STEVØ)201,200,201
  200 WRITE ØUTPUT TAPE 3,6,KASE,KØDE,M,W,PJW,VC,TRAV,PMAX,PØPR,ETA,RHØ,
     1U,V,AØ,Y,AREA
    6 FØRMAT(1H1,50X,9HI N P U I//5X,7HCASE = I1/5X,18HPRØPELLANT CØDE =
     1 I2/5X,21HCØDE FØRM FUNCTIØN = I1,6H       /5X,16HWEAPØN W (MM) = F
     212.4/5X,22HPRØJ.WT. PJW (LBS.) = F12.4/5X,27HCHAMBER VØLUME VC (C.
     3IN) = F12.4/5X,19HTRAVEL TRAV (IN) = F12.4/5X,26HMAX PRESSURE PMAX
     4 (PSI) = F12.4/5X,32HØPERATING PRESSURE PØPR (PSI) = F12.4/5X,32HP
     5RØP. CØVØLUME ETA (C.IN/LBS) = F12.4/5X,31HPRØP. DENSITY RHØ (LBS/
     6C.IN) = F12.4/5X,29HPRØP. FØRCE F (FT.LBS/LBS) = F12.4/5X,24HPRØP.
     7 CØNSTANTS A,AØ, = F12.4,5X,F12.4/5X,18HBURN.CØNSTANT B = F12.8/5X
     8,12HBØRE AREA = F12.4)
      WRITE ØUTPUT TAPE 3,20,(PH(I),DELTA(I),CH(I),PØP(I),XIM(I),GAMMA(I
     1),ZS(I),VM(I),S(I),T(I),WEB(I),I=1,N)
   20 FØRMAT(1X//50X,11HØ U T P U T//102H     PHI    L.DENSITY      CHARGE
     1    PPØ         XIM   GAMMA    ZS      VELØCITY         S        T
     2  WEB//(1X,F8.2,1X,F8.3,1X,F10.2,1X,F12.4,1X,F8.3,1X,F6.3,1X,F6.3
     3,1X,F12.3,1X,F8.3,1X,F8.3,1X,F12.9))
      WRITE ØUTPUT TAPE 3,7
    7 FØRMAT(1X//30X,57HTHE PØINT ØF ØPTIMUM EFFICIENCY IS WHEN S AND T
     1ARE EQUAL)
      IF(STEVØ)40,32,40
   32 N4=2
      N5=1
      DØ 30 I=1,N
      IF(S(I)-T(I))29,27,25
   25 AB(I)=100.
      N5=2
      GØ TØ 30
   27 WRITE ØUTPUT TAPE 3,28,PH(I),S(I)
   28 FØRMAT(1X//30X,6HPHI = F12.3,15H SINCE S = T = F12.4)
      N4 = 1
      GØ TØ 30
   29 AB(I) = ABSF(S(I) - T(I))
      VALUE=AB(1)
   30 CØNTINUE
      GØ TØ(40,35),N4
   35 DØ 23 I=1,N
      VALUE=MINIF(VALUE,AB(I))
   23 CØNTINUE
      K=10
```

```
      DØ 24 I=1,N
      IF(AB(I)-VALUE)24,26,24
   26 K=I
   24 CØNTINUE
      IF(K-10)950,951,951
  951 WRITE ØUTPUT TAPE 3,952,PH(1),S(1),T(1)
  952 FØRMAT(1X//20X,22HTRUE PHI IS LESS THAN F12.4,11H WHERE S = F12.4,
     1,9H AND T = F12.4//)
  961 PH(1) = PH(1) - 0.05
      IF(PH(1)-0.05)40,970,970
  970 N=1
      STEVØ=2.0
      GØ TØ 31
  950 IF(STEVØ)900,905,900
  900 IF(K-2)201,201,902
  905 WRITE ØUTPUT TAPE 3,33,PH(K),S(K),T(K)
   33 FØRMAT(1X//20X,25HTRUE PHI IS GREATER THAN F12.4,11H WHERE S = F12
     1.4,9H AND T = F12.4//)
  902 IF(PH(K)-1.0)41,40,40
   41 IF(PH(K)-PH(1))40,42,43
   42 IF(PH(1)-0.95)50,51,51
   51 PH(1) = 1.0
      N=1
      GØ TØ 48
   50 IF(PH(1)-0.90)53,52,52
   52 PH(1)=0.95
      PH(2)=1.0
      N=2
      GØ TØ 48
   53 PH(1) = PH(1) + 0.05
      PH(2)=PH(1) + 0.05
      PH(3) = PH(2) +0.05
      N= 3
      GØ TØ 48
   43 IF(PH(K)-0.95)44,45,45
   45 PH(1) = PH(K) + 0.05
      N=1
      GØ TØ 48
   44 IF(PH(K) - 0.90)46,47,47
   47 PH(1) = PH(K) + 0.05
      PH(2) = PH(1) + 0.1
      N=2
      GØ TØ 48
   46 PH(1) = PH(K) + 0.05
      PH(2) = PH(1) + 0.05
      PH(3) = PH(2) + 0.05
      N= 3
   48 STEVØ = 1.0
      GØ TØ 31
  201 WRITE ØUTPUT TAPE 3,202,(PH(I),DELTA(I),CH(I),PØP(I),XIM(I),GAMMA(
     1I),ZS(I),VM(I),S(I),T(I),WEB(I),I=1,N)
  202 FØRMAT(1X//(1X,F8.2,1X,F8.3,1X,F10.2,1X,F12.4,1X,F8.3,1X,F6.3,1X,F
     16.3,1X,F12.3,1X,F8.3,1X,F8.3,1X,F12.9))
      IF(STEVØ-1.)40,920,960
  960 IF(S(1)-T(1))40,27,961
  920 DØ 921 I=1,N
```

```
      IF(S(I)-T(I))921,921,922
922   N5=2
921   CØNTINUE
      IF(N5-2)32,40,40
 40   GØ TØ 1
      END(1,1,0,0,0,0,1,1,0,0,0,0,0,0,0)
```

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ABSTRACT DATA

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A DIGITAL COMPUTER PROGRAM FOR HIRSCHFELDER INTERIOR BALLISTICS

Forrest L. McMains

Technical Memorandum 1404, April 1964, 31 pp, tables. Unclassified report from the Artillery Ammunition Laboratory, Ammunition Engineering Directorate.

A digital computer program was written which will perform interior ballistic calculations on an IBM 709 or IBM 7090. A brief description is given as well as an outline of the method of analysis which this program uses. Examples are presented and both input and output formats are discussed.

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Ballistics -- Interior

A Digital Computer Program for Hirschfelder Interior Ballistics

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